A ROADMAP TO CERTIFY FLYING CARS

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ABSTRACT

Aircraft certification can act as a barrier for promoting rapid integration of emerging technologies. Urban Air Mobility (UAM) aircraft, think flying taxis, challenge the existing certification process due to novel features and a combination of functions, such as distributed electric propulsion/tilt-wing propulsion, vertical take-off and landing (VTOL), [flight] autonomy software, optionally piloted, energy storage, and the ratio of aircraft to pilots being below one. Certification can delay deployment of the technologies as they go through the certification process that may take several years and can increase costs of deployments if the burden of compliance is high. Certification can also be an enabler as it provides passengers comfort that the standard for safety is sufficiently high. One aspect of the FAA's challenge is that technology moves at the speed of innovation while the administrative rulemaking process, by design, does not. To address this challenge, this proposal is technologically neutral, with the understanding that technology and applications will evolve in the time between the publication of this proposal and the final rule, and beyond.

TABLE OF CONTENTS

List of Figures and Tables

1 INTRODUCTION

The concept of Urban Air Mobility (UAM) may appear to be a futuristic reference to an episode from the Jetsons; however, this aerial passenger services practice has been around since the mid-1950s with New York Airways (NYA) & Pan American. For reference, in June 1964, more than 30 flights were offered by NYA between John F. Kennedy (JFK) and Newark Liberty International Airports, with stops at locations such as Wall Street, averaging $4-11 ($32-$88 in 2018) for one-way fares[1]. Annually, they served approximately 500,000 passengers. Furthermore, in 1965, heliport operations began from the New York City Pan Am Building, operating with aircraft such as the Boeing Vertol 107 and various Sikorsky variants, including the S-61. Public perception pressured the NYA operations from the Pan Am Building, citing noise and safety concerns; however, they continued operations throughout 1964 and received approval for a 5-year permit.

Pan Am first/last mile connecting flights between New York/Newark and JFK airport occurred from 1965 to 1968, resuming in 1977. On May 16th, 1977, according to the NTSB Aircraft Accident Report 77-9, a fatal accident occurred[2]. The right landing gear of a NYA Sikorsky S-61L failed on the rooftop of the frequented Pan Am Building, killing four passengers waiting to board the aircraft as well as one pedestrian on the sidewalk below who was killed by a separated rotor blade. The NTSB determined the final cause of the accident to be fatigue failure on the landing gear tube assembly. All fatalities were determined to be caused by the operating rotor blades as a result of the collapse of the main landing gear[3].

During the peak time for helicopter operations in New York City in 2010, roughly 80,000 annual (approximately 219 daily) flights occurred. Moreover, public outcry for noise, emissions, and safety led to a close to 50% reduction in flights in 2017.[4] The Pan Am helicopter accident is a prime example of how new societal barriers emerge and still exist today when discussing Urban Air Mobility (UAM). NASA defines UAM as “a safe and efficient system for air passenger and cargo transportation within an urban area, inclusive of small package delivery and other urban Unmanned Aircraft Systems (UAS) services, that supports a mix of onboard/ground-piloted and increasingly autonomous operations.” The promise of UAM is multi-faceted, aiming to decongest road traffic, improve mobility, reduce transport time, decrease pollution, reduce strain on existing public transport networks, and reduce traffic accidents. The evolution of this concept has led to cross-platform technology and business transactions, with over $1 billion of investments in this industry as of September 2018[5]. These advancements are ensuring the continued safety track record of the aviation industry through this aerial transportation transformation.

To improve upon safety for this new era of aviation transportation, we should investigate why aircraft crash. According to NTSB aviation data, many aviation accidents are from inexperienced private pilots, and those flying warbirds, antiques, and experimental aircraft. This is depicted in Figure 1.

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1 Adam Cohen, UC Berkley. “Urban Air Mobility A Brief History and Overview of Societal Barriers.” *Webinar, September 18, 2018 (Time 6:02).* https://www.youtube.com/watch?v=AahMPkQsujI

2 National Transportation Safety Board (NTSB). “Aircraft Accident Report - New York Airways, Inc., Sikorsky S-61L, N619PA Pan Am Building Heliport, New York, New York, May 16, 1977.” *AAR-77-9, October 13, 1977.*

3 NTSB. *AAR-77-9.*

4 The New York Times. “Flying Chariot of the Wealthy, Noisy Bane of the Earthbound.” *October 5, 2011.*

5 Booz Allen Hamilton. “Urban Air Mobility (UAM) Market Study.” 2018. 6.

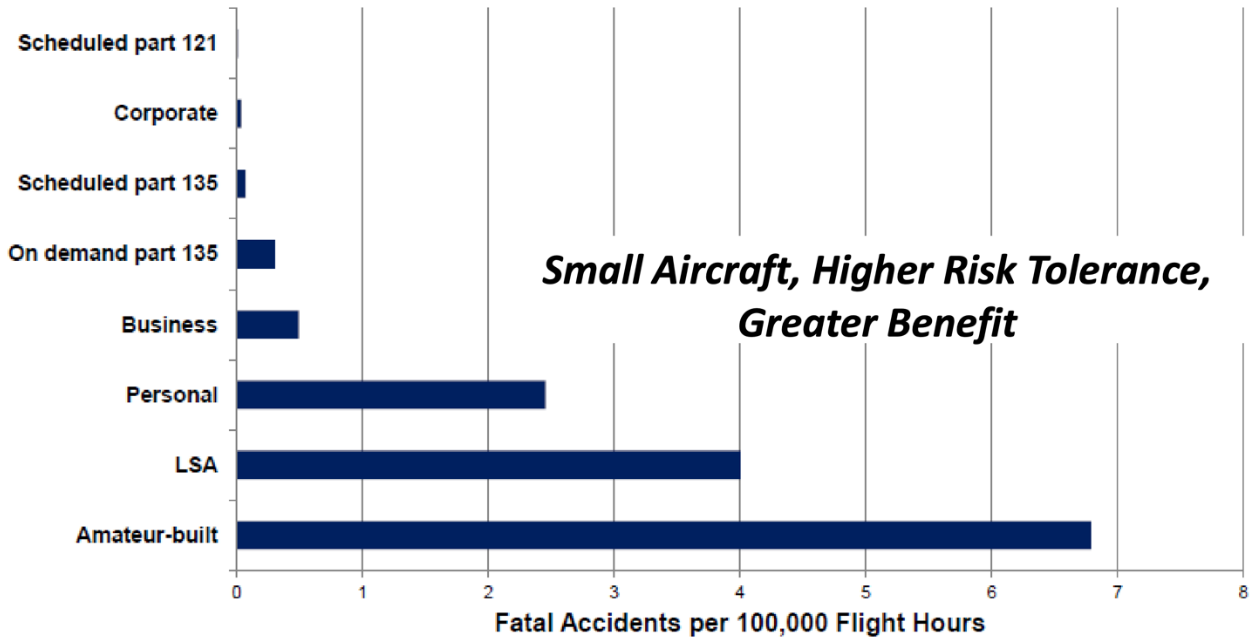

Figure 1: U.S. aviation fatal accident rates from 2005-2009[6]

1.1 Urban Air Mobility (UAM) Challenges and Strategies

In a UAM market study submitted to NASA by Booz Allen Hamilton, barriers and challenges are arranged by market maturity and the respective technology applicability/mitigation, as displayed in 2 below.

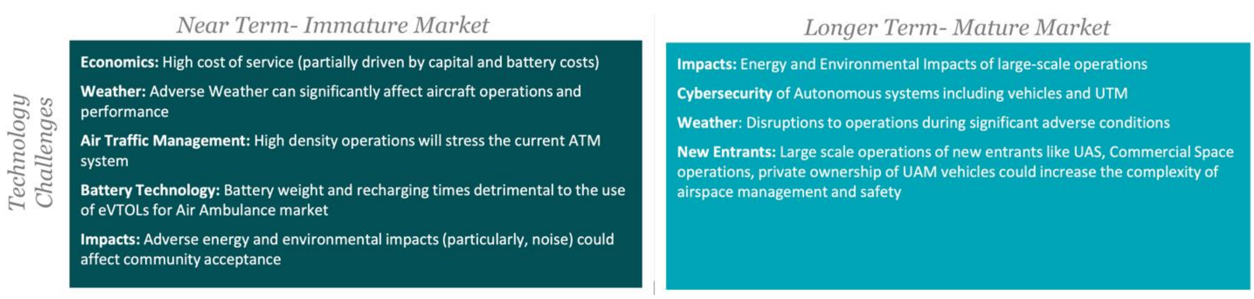

Figure 2: Key challenges by market maturity and technology

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6 NASA. "SVO." 9.

As the market matures, increasing the number of operations will challenge the current Air Traffic Management (ATM) system. However, initiatives such as the Air Traffic Management eXploration project (ATM-X) will introduce new technology to enable the safe integration of UAM into the National Airspace System (NAS). Another strategy that may allow for the success of UAM is new propulsion technologies that are undergoing tests by more than 70 manufacturers worldwide, varying from all-electric battery-powered to hybrid vertical takeoff and land (VTOL) aircraft. Furthermore, another longer-term challenge to ensure UAM is a viable mode of transportation is overcoming societal barriers.

2 TECHNOLOGY OUTPACING REGULATION

Aviation standards are enacted based upon strenuous tests, procedures, operations, and failures. Introducing a new era of aviation with UAM introduces further complexity and opportunities for both industry and policymakers alike. The UAM market will experience technical and legal headwinds along system failure management and redundancy but politicians are creating collaborative opportunities like the NASA UAM Grand Challenge, the FAA UAS Integration Pilot Program, and the FAA Rulemaking Committees, to align technology and regulations.

2.1 How UAM is Different

All eyes are on UAM because of the breadth of challenges it poses and the numerous touchpoints it has within the aviation environment, especially regarding ATC/ATM and flight standards. In a 2015 On-Demand Mobility (ODM) workshop in Kansas City, NASA Senior Research Engineer Ken Goodrich, and Senior Advisor for On-Demand Mobility Mark Moore presented how technology has simplified piloting[7]. They stated that "operationally the change has been tremendous, improving utility, efficiency, average workload, comfort, potential safety, etc." They cited various technologies including GPS navigation, high-performance autopilots, terrain/obstruction awareness, weather information pre and in-flight, higher component reliability, and improved system monitoring/failure detection.

Moreover, a key finding from the NASA UAM market study states that "current legal framework does not address issues related to operations over people, beyond visual line of sight, commercial operations carrying cargo or people, and airworthiness certifications. Assured autonomy remains a challenging technical and legal problem". This paper focuses on airworthiness; however, we recognize there may be other shortcomings. The recent FAA Reauthorization Act of 2018 is a testament that the current legal framework is evolving to align with technology advancements such as demonstrated by allowing for more operational flight scenarios with small (under 55lbs) unmanned aircraft systems (UAS).

Determining the applicability of FAA certification standards divided between UAM aircraft proves challenging but is understood better through scenario analysis. The fundamental issue of the absence of evidence is not proof of deficiency (self-driving Ubers were safe and accident-free for millions of miles before a tragic accident brought it in the public eye). Industry key players need to think across several dimensions: engineering, human factors, anatomy. Gaps need to be identified and addressed concerning airframe, power plant, and avionics in three overarching categories of certification: Airworthiness, Operations, and Crew Qualifications.

7 Ken Goodrich, Mark Moore [NASA]. "Overview: Simplified Vehicle Operations (SVO)." 2015. 14.

2.1.1 QUESTIONS CONSIDERED IN THIS ANALYSIS:

- How are new aircraft certified?
- What is the preferred path to certification for UAM aircraft (e.g., Part 23, 27, 21.17(b))?
- What are the gaps in requirements and means of compliance (e.g., RTCA DO-178C, ASTM F39)?
- What is being done to address these gaps?

2.1.2 CERTIFICATION FOR MANNED AIRCRAFT

This analysis focuses on airworthiness certification, which addresses safety risks by setting requirements for aircraft design, manufacturing, performance, failure response, and maintenance. This applies to safety-critical features, such as aircraft structure, engines, propellers, software, and electronics. Regulatory agencies develop requirements for airworthiness. Applicants must meet these requirements through "means of compliance," based on regulatory guidance. In some cases, the certification authority will accept industry consensus standards developed by the American Society for Testing and Materials (ASTM), the Society of Automotive Engineers (SAE), the Radio Technical Commission for Aeronautics (RTCA), and others as means of compliance.

Aircraft certification can act as a barrier for promoting rapid integration of emerging technologies. UAM aircraft challenge the existing certification process due to novel features and a combination of functions, such as distributed electric propulsion/tilt-wing propulsion, VTOL, autonomy software, optionally piloted, energy storage, and the ratio of aircraft to pilots being below 1. Certification can delay deployment of the technologies as they go through the certification process that may take several years and can increase costs of deployments if the burden of compliance is high. Certification can also be an enabler as it provides passengers comfort that the standard for safety is sufficiently high. Our research identified trust in technology as a critical societal barrier)[8].

Aircraft certification is organized by category and classes of aircraft, which determine the risk regime that they reside. Certification requirements differ by class and influence the design of aircraft and heliports. The overall process is driven by identifying risks, which may be based on the aircraft and the intended operation. For example, the following are requirements after the critical loss of thrust:

- Transport category, airplane class: Certified to <u>2.4 – 3 percent climb gradient</u>
- Transport category A, rotorcraft class: Certified to <u>100 ft/min climb rate</u>
- Normal category, rotorcraft class: <u>no min climb rate</u>

[8] "UAM Market Study." 2018. 28.

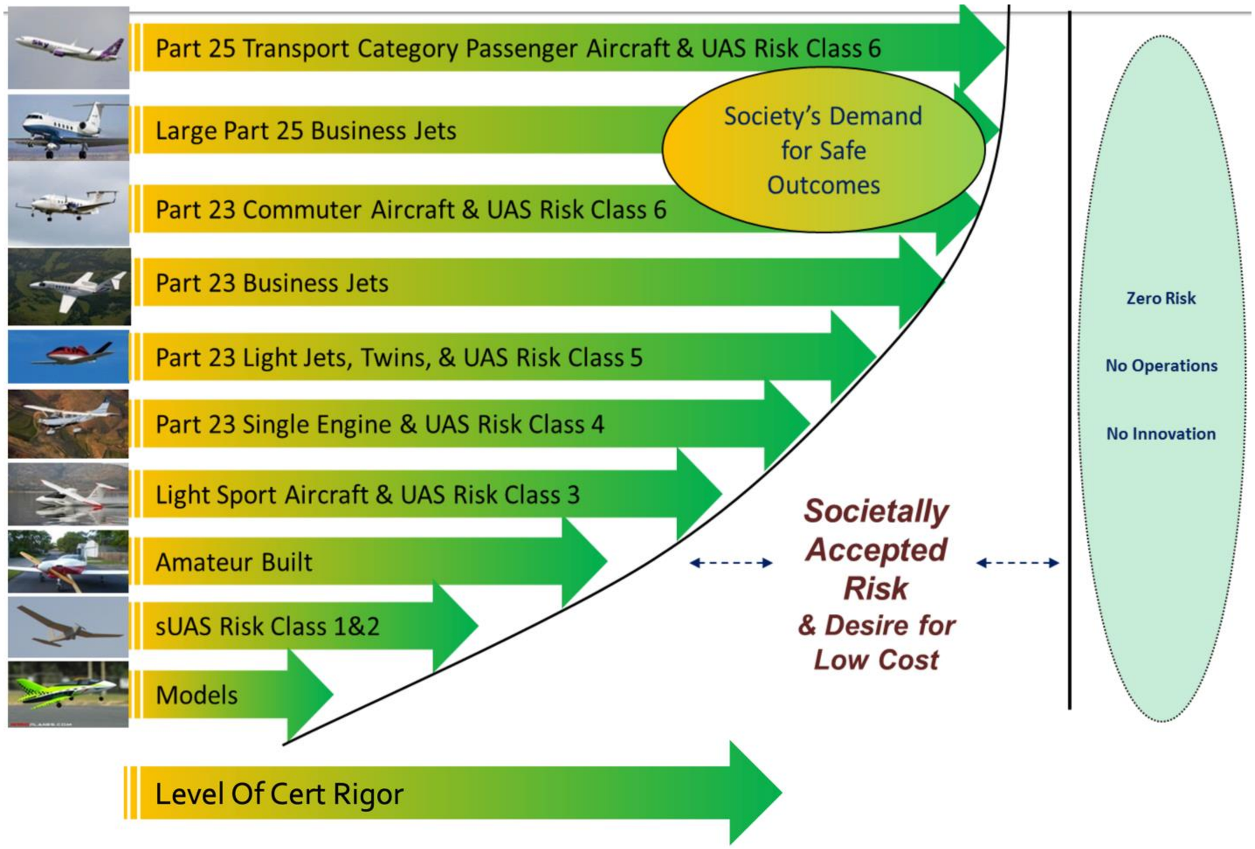

Figure 3: Trade-off between risk tolerance and level of certification rigor[9]

UAM aircraft may vary in weight, type of service, propulsion, number of passengers, and speed, which may change their path to certification. New aircraft designs for UAM may have multiple ways to certification with FAA, as depicted in Figure 3. The traditional Part 21.17(a) method is used for aircraft that fall within existing categories, such as fixed-wing or traditional rotorcraft. Additional requirements and special conditions may apply. For example, aircraft certifying under Part 23 or 25 must also comply with Part 33 Engine and Part 35 Propeller if applicable. For aircraft that do not fall into existing categories, Part 21.17(b) may be used. This path is not meant for mass production, so eventually, an update to the regulatory framework may be needed for large-scale UAM deployments of aircraft that take this path. The General Aviation Manufacturers Association (GAMA) suggests that there are "regimes" for certification paths based on an aircraft's likeness to a wing-borne aircraft or a rotorcraft. The FAA is continuously reviewing and updating this regulatory framework.

9 Tom Gunnarson. *Aircraft Type Certification Considerations, January 2018.* AHS TVF Workshop. https://vtol.org/files/dmfile/13-TVF5-2018-Gunnarson-ASTM-Jan191.pdf.

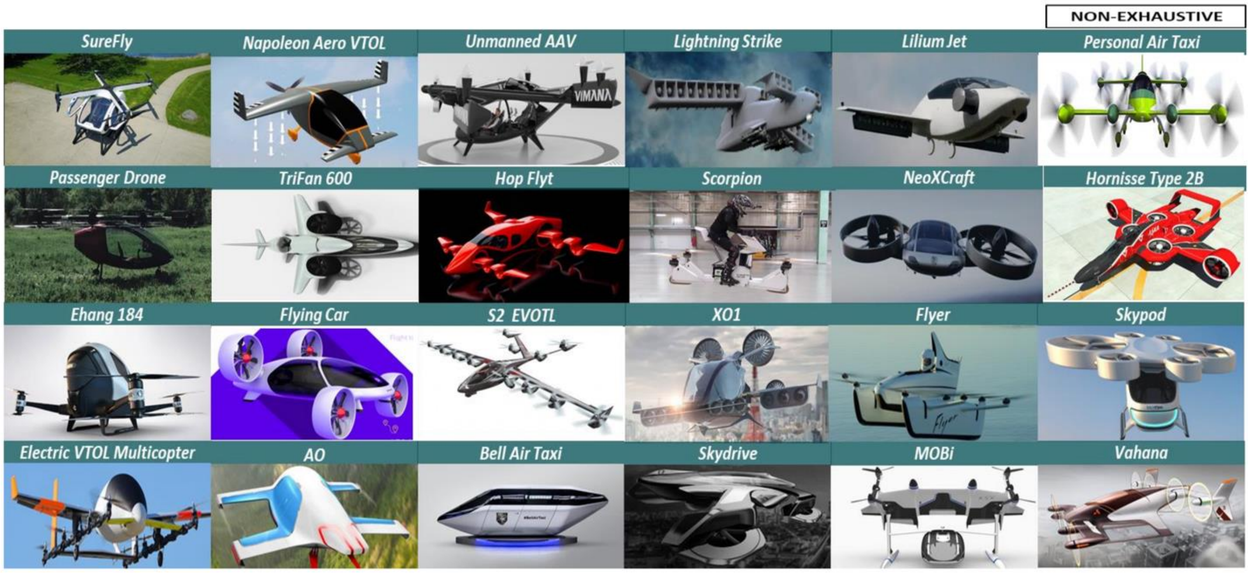

Figure 4: Various UAM aircraft types and designs[10]

For example, there are three experimental type certification projects underway for aircraft ranging from 10 to 6000 lbs., for both manned and unmanned systems. As viewed in the non-exhaustive table in Figure 4, various types and forms of UAM aircraft exist today. Part 23 Amendment 64 was updated in August 2017 to provide higher-level requirements and allow industry consensus standards to fill in the more detailed requirements. The amendment, which took nearly 10 years, reduced 377 regulations to 71, with a heavy reliance on consensus standards. This demonstrated the shift from prescribing detailed regulatory requirements to prescribing high-level requirements. It does not prescribe specific technical solutions or have various categories. Recently, FAA Order 8000.71 defines a Hybrid vehicle, "a heavier-than-air aircraft that is supported at vertical takeoff, vertical landing, and low-speed flight by the dynamic reaction of the air against its rotors or thrust and in horizontal flight by the dynamic reactions of air against its wings (i.e., the tilt-rotor aircraft)."[11]. Clear definitions will allow for a more straightforward pathway during certification, by clearly identifying where UAM aircraft belong.

3 INNOVATIVE TECHNOLOGIES

Overview of the technologies that need to be addressed before commercial feasibility.

3.1 Emerging Technology Safety

The UAM industry plans to adopt autonomous operations, without onboard pilots, using highly sophisticated software and artificial intelligence (AI) onboard instead, but are non-deterministic, meaning that even for the same input, the algorithm may exhibit different behaviors on different flights. This is a

[10] "UAM Market Study." 2018. 6.

[11] US DOT, FAA. "National Policy, Order 8000.71." *Aircraft Make, Model, and Series Taxonomy, May 2, 2017*. 9.

generalized concern under the broader topic of explainable and verifiable AI. To address this, experts from NASA identified a concept of Simplified Vehicle Operations (SVO) whereas there is a transition period from expert pilots to trained operators to users of UAM aircraft. These aircraft will reduce failures attributed to pilot error by digital fly-by-wire systems, evolving into full autonomy[12]. Cameras and other exterior systems attached to the UAM aircraft will identify obstacles onboard during the flight, and will alert the pilot/autopilot to avoid the identified obstacle, will increase the overall safety for the passengers, surrounding infrastructure, and non-involved participants on the ground. Onboard safety sensors could also monitor the mechanical safety of the aircraft by automatically logging component utilization. In turn, factoring in various external factors like weather, operational environment, and landing area, allowing engineers to program onboard computer systems to schedule preventative and overhaul maintenance; therefore, potentially avoiding the disastrous scenario in 1977 of the structural failure of the NYA helicopters' landing gear and death of both participating and non-participating personnel. Other challenging areas for emerging safety is for the adoption of propulsion and energy storage in an industry traditionally known for working with engines and liquid fuels. Risk mitigation modes with these new technologies will need thorough review to identify failure concerns with propellers, motors, electrical systems, and energy storage. New minimum equipment lists (MEL) will need to be documented, with redundancies and other mitigation factors well thought through and tested.

The laws are clear for operating an aircraft with a pilot, as they exist under 14 Code of Federal Regulations (CFR) Parts 21, 23, 25, 27, 36, 61, 91, and 119. UAM aircraft has automation and other advanced technology that will allow for truly autonomous operations in the next few decades, just as the Jetsons foreshadowed. However, ideal UAM operations require modification of current regulations, or new regulations altogether, including:

- Beyond visual line of sight (BVLOS) (waiver to 14 CFR Part 107.31)
- Operations over people, streets, etc. (waiver to 14 CFR Part 107.39)
- Carrying air cargo commercially and across state lines (addressed in Section 348 of the new FAA Reauthorization Act of 2018)
- Airworthiness for carrying a passenger or patient (14 CFR Part 23)
- Flights in instrument meteorological conditions
- Airworthiness certification of autonomous and remotely piloted aircraft
- Training and knowledge requirements for pilots and operators (addressed in Section 349 of the new FAA Reauthorization Act of 2018)

Additional safety measures:

- Motor Redundancy (i.e. eVolo Volocopter 18 prop-rotor)
- Automatic Ground Collision Avoidance (i.e., F-16 system)

People make entire careers out of navigating each of the above certification standards. Certification is a highly technical and process driven activity that requires institutional knowledge. While these are U.S. certifications, it should be noted that several UAM aircraft manufactures are targeting international airworthiness certifications before entering the U.S. market. Even though there are differences in airworthiness requirements, the European Union Aviation Safety Agency (EASA) and the U.S. take efforts to harmonize regulations.

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12 NASA. "SVO." 2-3, 14, 22-26.

3.2 Vehicle Performance

Analysis conducted in the Uber Elevate Whitepaper explains the benefits of Distributed Electric Propulsion (DEP) on UAM VTOLs. The aircraft will use multiple electric motors, controllers, and a redundant battery: *"A VTOL will typically have a Thrust/Weight of 1.15 or greater to provide extra power for climb and a control power margin. This Thrust/Weight ratio is typically measured at the continuous power rating. While turbines and piston engines are often able to provide a short time emergency rating that provides a 10-20% increase in power, electric motors are typically able to produce an additional 50%+ power for 1-2 minutes until they overheat. These peak ratings aren't accounted for in the Thrust/Weight, but reserved for emergency operation such as failure of a motor."*[13]

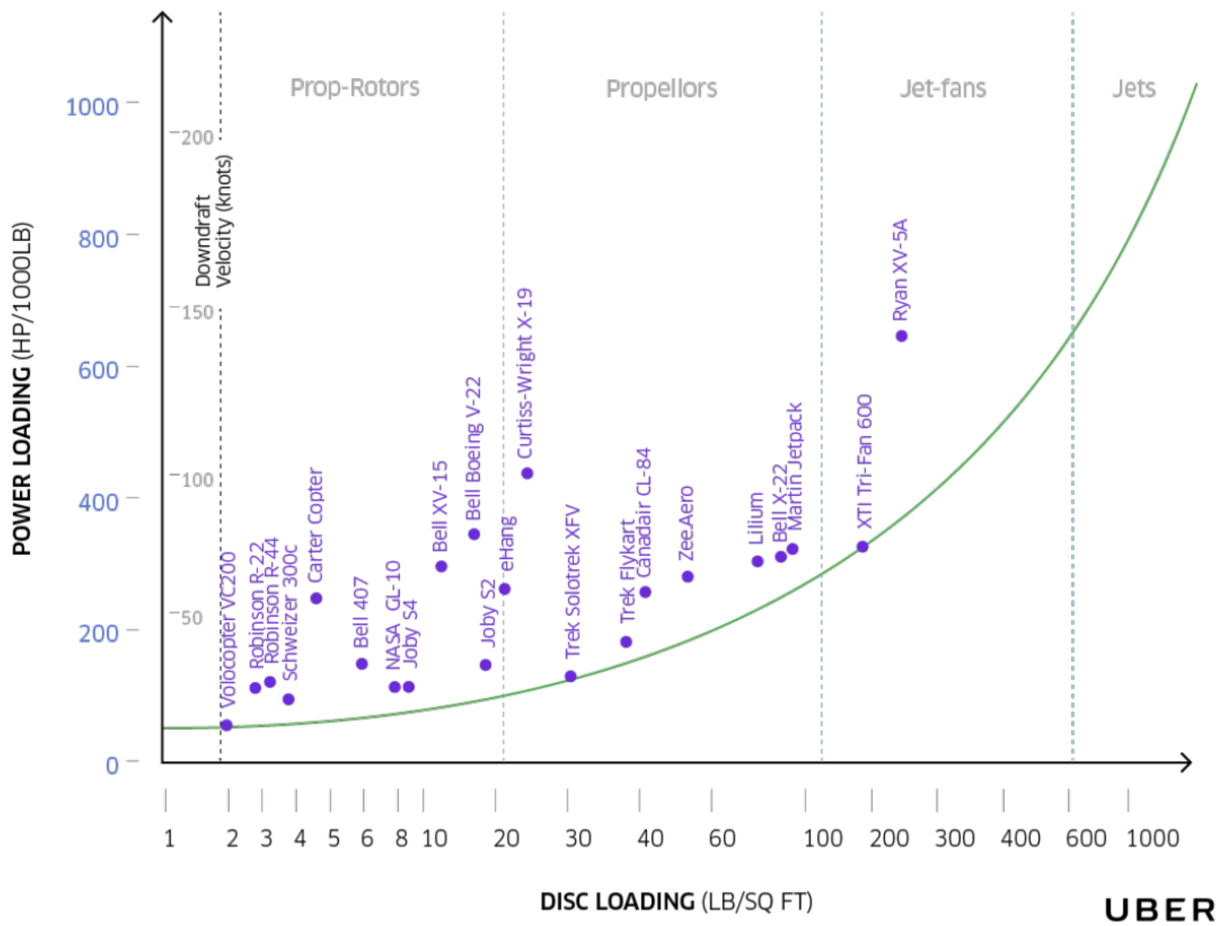

Figure 5: Distribution of disc loading attempts by past and recent vertical lift vehicles[14]

It's important to note that UAM aircraft are not necessarily meant to travel long distances or be more efficient than current airplanes or helicopters but should be so redundant that the margin of safety is orders of magnitudes better than current general aviation aircraft. As inferred from Figure 5, the efficiency improvements also have a side-benefit of reduced sound output, but more so because UAM aircraft are

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[13] Uber Elevate. "Fast-Forwarding to a Future of On-Demand Urban Air Transportation." *October 27, 2016.* 20.

[14] Uber Elevate. 20.

higher performing than traditional aircraft potentially allowing for full acceptance, moreover, with the caveat of refinements to the current certification process.

4 CHALLENGES/GAPS

4.1 Overview of the Certification Regime

This table outlines some current gaps but captures ongoing activities to create a viable UAM certification path.

Requirement	Relevant Documents	Gap	Relevant Activities
All Aircraft: Functional Hazards	FAA 23.1309-1E, AR 70-62, MIL-HDBK-516C	Identification of hazards, design methods to address hazards, and testing methods	ISO-21448 SOTIF
All Aircraft: Risk Assessment and Management	FAA Order 8040.4A, SAE ARP 4761, MIL-STD-882E	New flight modes and characteristics, unclear risk profiles	
Part 33/ CS-E: Electric Propulsion	ASTM F39.05 *Electric Propulsion Units*	Design and manufacture issues	Proposed Revision (WK47374)
Part 33/ CS-E: Electric Propulsion	ASTM F44.40 *Powerplant*	Integration issues for hybrid-electric propulsion	Proposed Revision (WK41136)
Part 33/ CS-E: Electric Propulsion	ASTM F39.05 *Electric Propulsion Units*	Energy storage systems	Proposed Revision (WK56255)
All Aircraft: Software Design Assurance	RTCA DO-178C	The methods are unable to handle the large number of states and decisions that autonomy algorithms can take	
Detect and Avoid (DAA)		Minimum Operational Performance Standards (MOPS) to specify DAA equipment to support BVLOS UAS operations in Class D, E, and perhaps G, airspace.	RTCA SC-228
Command and Control (C2)	RTCA DO-362	Normative performance standards for C2 link systems and constituent subsystems, including beyond radio line of sight (BRLOS).	

Figure 6: Summary of critical standards, gaps, and activities

The process is driven by identifying risks, which depends on the aircraft and its intended operation, typically organized by classification. It's noted that safety requirements transform into risk controls for a product or article. A safety requirement in the form of an airworthiness regulation is a safety risk control that, when complied with, constitutes an acceptable risk. When uncovering systematic hazards, Airworthiness Regulations become enacted, because the related outcome(s) have an unacceptable risk. Part 33: Engines, eludes to references of gas turbine engines, so we will need to determine how to incorporate electric motors and hybrid propulsion technologies.[15]

5 PERFORMANCE-BASED REGULATION FOR UAM

5.1 Overview of the Certification Regime

As mentioned above, in its Notice of Proposed Rulemaking (NPRM) for Operation of Small Unmanned Aircraft Systems Over People, "the FAA recognized that the possibilities for innovation in unmanned aircraft technology are virtually boundless and that the industry can move in directions no one can predict."[16]

The FAA explained: One aspect of the FAA's challenge is that technology moves at the speed of innovation while the administrative rulemaking process, by design, does not. To address this challenge, this proposal is technologically neutral, with the understanding that technology and applications will evolve in the time between the publication of this proposal and the final rule, and beyond.[17]

The FAA's NPRM is consistent with the principle of performance-based regulation, which "focuses on desired, measurable outcomes, rather than prescriptive processes, techniques, or procedures."[18] As discussed above, the FAA's current "regimes" of type certification for aircraft, which impose thousands of pages of prescriptive processes, are inconsistent with performance-based regulation. Depicted in Figure 7, this new certification approach will account for the broad spectrum of fixed-wing or rotary aircraft.

15 71 Federal Register 5769. *February, 2, 2002.* 28.

16 84 Federal Register 3856, 3857. *February 13, 2019.* 107.

17 84 FR 3856, 3857.

18 U.S. Nuclear Regulatory Commission. "Performance-based Regulation." *NRC Library, Glossary, March 21, 2019.*

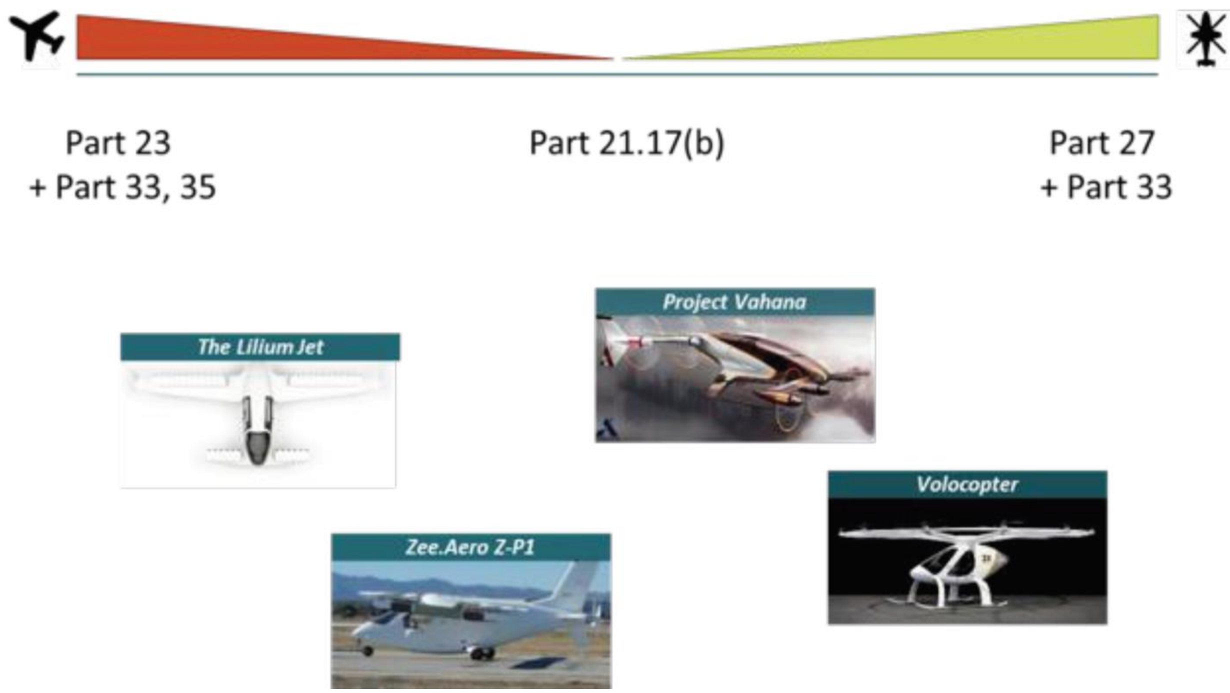

Figure 7: UAM concept vehicles may fall along a spectrum ranging from resembling fixed-wing or rotary aircraft[19]

So where should the FAA go from here? As seen in the pictures throughout this paper, UAM will involve a wide variety of wild, Jetson-esque future vehicles, which, as stated in Section 3.1, should be safer through their use of advanced technology. However, the current certification regime is prescriptive and based on inferior current technology, so this approach to certification is not appropriate for UAM. The FAA, by shifting to performance-based regulation, as seen in the 2019 NPRM for small UAS, has begun to adapt its approach in a helpful way. The FAA should, because of the inherent safety features and potential for bold, unpredicted innovation of UAM aircraft, use this approach of performance-based regulation for airworthiness certification of future vehicles.

19 "UAM Market Study." 2018. 15.

6 NEXT STEPS

As UAM operations take off in the next decade, a broader international strategy and certification consensus needs further investigation because flights in San Jose, California, for example, may not translate to operations in São Paulo, Brazil. In the U.S. the existing regulatory framework allows for testing to evaluate various flight operation use-cases in pre-determined flight zones, through Certification of Authorizations (COAs). Moreover, preliminary research has evaluated some areas within the U.S. such as Dallas, TX and San Jose, CA, for specific use tests. Performance and market requirements in various regions need detailed analysis, investigation of the human factors, duration of flights, and alternate power. This will allow for a holistic evaluation of UAM operations to assist in the ongoing modification and creation of regulations.

As outlined above, many in the aviation community see Part 23 Amendment 64 as an opportunity to develop detailed design standards through consensus standards for flight characteristics, performance, operating limits, structures, design, powerplant, propulsion, and energy storage. However, what is needed from consensus standards to fill the gap for UAM aircraft are:

- Making tiers where it makes sense,
- Providing specific technical solutions that do not restrict innovation,
- Providing test specifications that allow for creating new technology, and
- Providing specific compliance methods to best ensure safety.